9.0 RESOURCE TESTING

Production tests were performed during the summer of 1979. Results of these test are as follows:

- Static water level below ground surface (BGS).........421'
- Position of a TRW Reda 120 hp pump BGS..............1,000'
- Pumping rate - - gallons per minute (GPM)............315
- Drawdown BGS...777'
- Water temperature at the surface.....................125°F
- Estimated sustained maximum production (GPM).........400
- Average total dissolved solids (TDS).....± 6000 milligram per liter (mg/l)

The production well was reworked during the fall of 1980 and a more comprehensive test of the resource was performed on December 17, 18, and 19 of 1980 by two Radian Corporation hydrogeologists.

This test was used to define the well characteristics and aquifer parameters as listed in this section of the report. The results of this test were compiled and presented by Radian Corporation in a report entitled "Geothermal Injection and Production Well Results at Navarro College", February 14, 1981. A copy of this report may be obtained from the U.S. DOE Technical Information Office. A chemical analysis of the resource water is listed in the appendix.

9.1 Apparatus

A 40 horsepower submersible pump was installed in well number 1 and a temporary transformer installed to convert the available 1320 volts AC to 480 VAC required by the motor. Fifty feet of 3 inch PVC pipe was used to route the water over a small berm and away from the wellhead. Flow was controlled by a 2 inch gate valve at the wellhead.

A four foot section of 4 inch pipe with a 2 inch free discharge orifice was attached to the end of the PVC pipe and used to measure flow. A 0.0625 inch hole was drilled in the top face of the orifice plate in an attempt to vent evolved gases from the upstream 4 inch pipe section.

Water levels were measured by use of a copper air line placed in the production well and attached to a pressure gauge.

9.2 Test Conducted

Data from this test was used in determining aquifer parameters of transmissivity, coefficient of storage, cone of depression, specific capacity, discharge temperature, chemical quality, and presence of dissolved gases.

The pump was turned on and allowed to clean and develop the well for twelve hours on December 17 and 18. The flow rate during development exceeded 100 GPM but was less than 165 GPM. The pump was turned off at 3 a.m. on December 18, 1980 and the water level in the well permitted to recover.

Based on the data collected, a 19 hour drawdown specific capacity of 0.99 and an estimated 19 hour recovery specific capacity of 1.03 were calculated. The average value being 1.0 gallons per minute per foot of drawdown (GPM/ft. dd). The water levels during the 3.6 days of pumping are recorded and shown in the following table and show no significant change with additional pumping.

TABLE 9.2-I.

Date/Time	Pump Test Discharge Temperature (°F)	Time Since Pumping Began (Hours)	Pumping Water Level (Feet Below Measuring Point)
18 Dec. 1980			
6:00 PM	Pump turned on @100GPM	0	491
6:15	103.1		
:30	111.2		
:45	114.8		
7:00	116.6	1	570
:15	118.4		
:30	121.1		
:45	121.1		
8:00	118.4	2	571.5
:15	118.4		
:30	118.4		
:45	119.3		
9:00	118.4	3	578
:30	118.4		
10:00	120.2	4	580.5
:30	122.0		
11:00	122.9	5	586
:30	119.3		
12:00 Midnight	118.4	6	578
19 Dec. 1980			
12:30 AM	118.4	7	
1:00	118.4	7	580.5
:30	117.5		
2:00	116.6	8	581
3:00	116.6		
4:00	122.0	10	583
5:00	120.2		
6:00	122.0	12	585
7:35	122.0		

TABLE 9.2-1 (Cont.)

Date/Time	Pump Test Discharge Temperature (°F)	Time Since Pumping Began (Hours)	Pumping Water Level (Feet Below Measuring Point)
10:06	122.9	16	587
11:00	116.6		
12:00 Noon	122.9		
1:00 PM	122.9		
1:01	Pump turned off	19	588
10:00	Pump turned on for further well development @ ±100GPM		
21 Dec. 1980			
11:00 AM	123.8	37	586
22 Dec. 1980			
11:30 AM	123.8	61.5	596
23 Dec. 1980			
11:15 AM	123.8	85.5	596
12:00 Noon	Pump turned off end of pumping development		

Discharge Temperature During Navarro
College Geothermal Well Test
Table 9.2-1

The temperature of the discharging geothermal fluid was taken at hourly intervals during the course of the pump test and are also shown in Table 9.2-1. At the end of the 19 hour pump test, the discharge temperature was 122.9 degrees F but recovered in later tests to 123.8 degrees F.

During the test, field specific conductances were determined for pumped fluid samples and are presented in Table 9.2-2 along with dissolved gas notations. A water sample was collected on December 19, 1980 upon completion of the 19 hour test. Analysis of the sample for total dissolved solids (TDS) indicated a value of 6080 milligrams per liter (mg/l). Two previously recorded values of TDS were at 5300 mg/l and 6820 mg/l.

TABLE 9.2-2.

Date	Time	Hours of Pumping	Field Conductance (mhos/cm)	Conductance Sample Temperature (°F)	Remarks
12-18-80	7 P.M.	1	13,100	105.8	Clear discharge some gas bubbles.
	8	2	13,100	116.6	Clear discharge.
	9	3	13,400	114.8	Clear discharge.
	10	4	13,200	109.4	Clear discharge.
	11	5	14,000	110.3	Clear discharge, gas.
	12 mid.	6	15,000	112.1	Clear discharge with bubbles, distinct odor.
12-19-80	1 A.M.	7	14,500	113.0	Clear discharge.
	2	8	14,750	113.0	Clear discharge, lots of gas in discharge with distinct odor.
	3	9	15,000	104.0	Clear discharge, lots of gas in discharge with distinct odor.
	4	10	15,700	113.0	Clear discharge.
	5	11	15,500	113.0	Clear discharge.
	6	12	15,500	113.0	Clear discharge.
	8	14	15,700	112.2	Clear discharge.
	10.15	16.25	14,700	113.9	Clear discharge.
	12 Noon	18	15,500	114.8	Clear discharge.
	12:55	19	14,700	113.0	Clear discharge.
12-17-80	1 P.M.	19	End of Pumping Phase of Test		

Field Specific Conductances of Pumped Geofluids
Table 9.2-2

The computed average transmissivity value determined from the drawdown and recovery data of the 100 GPM test is 1360 gallons per day per foot (GPD/ft). This value is lower than the <u>average</u> Woodbine value of 2300 GPD/ft reported for Navarro County by the Texas Water Development Board, report number 160, but does not appear unreasonable as the production well is perforated only in the lower Woodbine formation of 81 feet average thickness. From this the average permeability is computed at 16.8 gallons per day per square foot (GPD/ft^2) (0.449 Darcy).

The coefficient of storage (a dimensionless number) is the amount of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. This parameter assists in determining how rapidly a cone of depression will expand with time. The average storage coefficient value computed from the test was 0.000024. Calculations indicate that the cone of depression caused by the pumping at the production well migrated radially out to about 2 miles during the course of the test assuming a practical sensible drawdown of 0.01 feet. No apparent hydrogeological boundaries were noted during the course of the test.

9.3 <u>Results</u>

All test objectives were met during the pump test of Well number 1 and no additional development is required. The geothermal fluid temperature of 123.8°F was within 2°F of the Spring 1979 test and is adequate to provide heating requirements of the cascade geothermal aquaculture system.

10.0 DISPOSAL WELL DRILLING AND LOGGING

10.1 Summary

During December of 1979, a second exploratory well was drilled on Navarro College property to determine if a hotter resource, of better quality, could be encountered. This would allow use of the first well as an injection well.

The second well was drilled to a total depth of 4762 feet. An electric log (see Appendix C) was run in the open hole from a depth of 4762 feet to within 2500 feet of the surface where previous logs had been run on the first well.

Only poorer quality resources were encountered and the hole was plugged back to a final depth of 2400 feet for use as the injection well. The well was then completed with perforations in the upper Woodbine Formation.

10.2 Completion

Prior to testing the disposal well at 3900 feet, a string of 8-5/8 inch casing was set and cemented at 4163 feet. Fluid yield and quality from this zone was not acceptable and the well was initially plugged back to 3300 feet and completed in the lower Woodbine Formation by perforating from 2452 feet to 2590 feet.

Testing was initiated to determine if there would be any interference with well number 1. When pumping in well number 2 was started, an immediate drawdown was noted in well number 1.

Because of this interference, well number 2 was plugged back to a depth of 2400 feet on December 23, 1981, for use as the injection well.

After the plug was set, the well was perforated in the upper Woodbine Formation with 4 shots per foot in the intervals 2234 feet to 2256 feet and 2278 feet to 2292 feet. A total of 36 feet of sand was perforated with 133 shots.

A standard non-pressure wellhead was installed (Fig. 10-1)

10.3 Stimulation Method

In an effort to increase the rate at which the disposal well would accept fluids at a low pressure, a hydraulic fracture treatment was performed on the upper Woodbine Formation sands on October 23, 1981. The method employs hydraulic pressure to fracture the rock and the introduction of sand into the fractures, preventing their closing after the pressure is released.

The formation broke down at a surface pressure of approximately 1500 pounds per square inch (PSI). Before all the sand could be pumped into the fractures, the formation quit taking the sand leaving a sand-gel mixture in the casing. The sand settled out of the gel and filled the casing to a point above the perforations.

On October 24, 1981, a coiled tubing unit was used to run a 1 inch outside diameter (O.D.) continuous tube into the well and nitrogen was employed to jet-lift the sand out of the casing. The sand was removed to a depth of 2309 feet, clearing all perforations.

NAVARRO COLLEGE GEOTHERMAL WELL #2

WELL HEAD

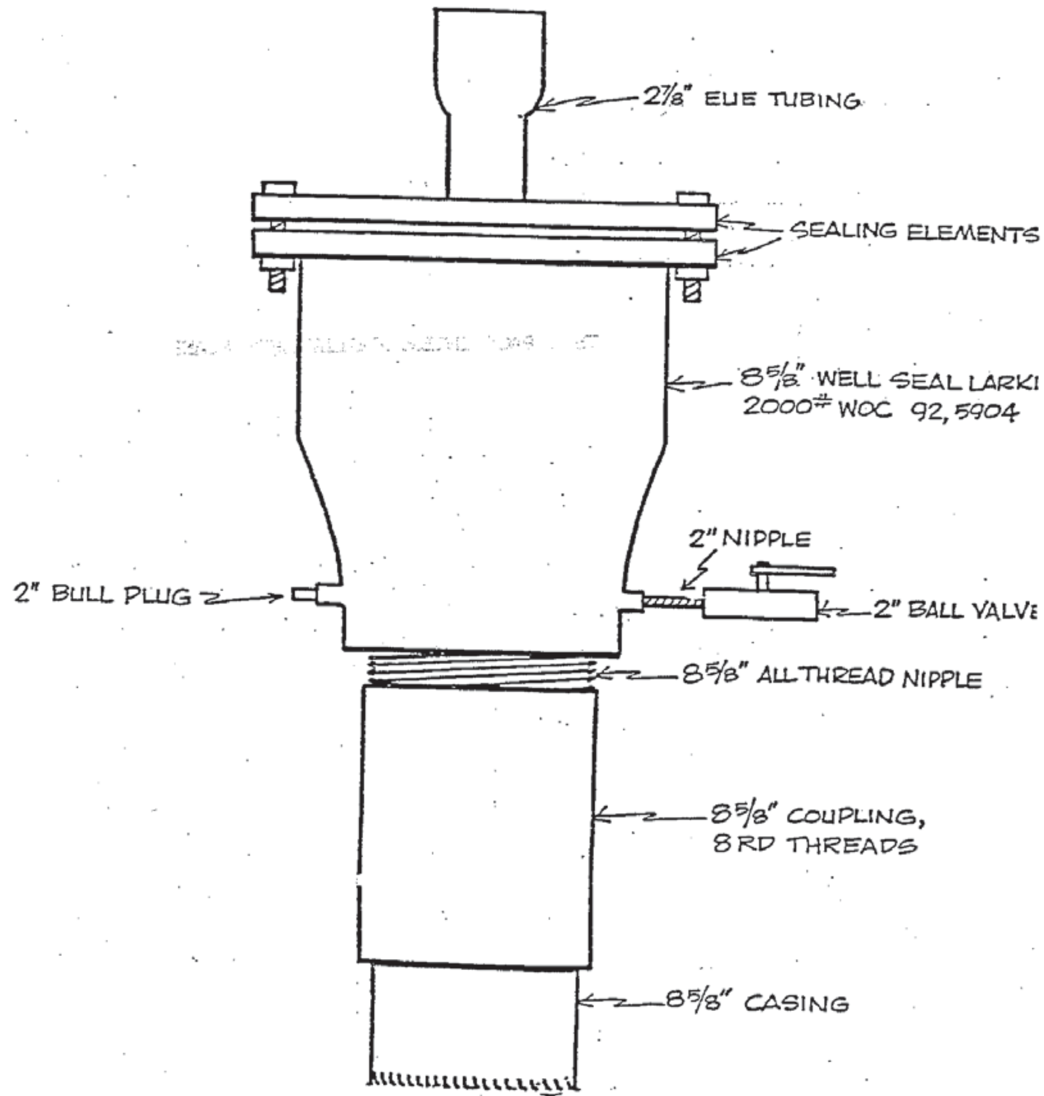

Figure 10-1

THIS PAGE INTENTIONALLY LEFT BLANK

11.0 DISPOSAL TESTING

On October 24, 1981, a pump truck was connected to the disposal well and water from a holding tank was pumped into the well. Pumping began at the rate of 255 GPM per minute at a constant pressure of 750 pounds. After 20 minutes of pumping at 750 pounds of pressure an attempt was made to determine the acceptance rate at gravity feed. A gravity injection rate of only 60 GPM was obtained. It was also determined that 500 pounds of pressure would be required to sustain an acceptance rate of 120 GPM.

THIS PAGE INTENTIONALLY LEFT BLANK

12.0 APPLICATION ANALYSIS

12.1 Technical

The Geo-Heat Center at Oregon Institute of Technology was given the limitation of the injection well and requested to determine the most feasible application for this resource. Preliminary engineering and design details performed by the Geo-Heat Center indicated that the most feasible application would be in an aquacultural/agricultural operation.

The Geo-Heat Center was provided with information on average daily, monthly, and yearly temperatures at Corsicana, Texas, plus an expected energy yield from the resource of 1.6×10^6 BTU/HOUR at 60 GPM flow and they determined that sufficient energy was available to maintain 0.5 acres of covered aquaculture ponds at an optimum prawn growing temperature of 82°F. In addition to the aquaculture operation, the center advised that sufficient energy would exist in the effluent from these ponds to provide necessary heat for space heating requirements of a small greenhouse unit.

In an effort to increase the economic viability of the project, it was determined that all effluents could be captured in a two acre reservior which could be utilized for a catfish production pond and possible irrigation of cropland.

With this preliminary engineering data available, Navarro College submitted a supplement to the original proposal in December of 1981 to the United States Department of Energy which received approval through Modification A005 to the original proposal, "Direct Utilization of Geothermal Energy at Navarro College, Corsicana, Texas".

This approval led to preparations of preliminary and Final Design Reports by a certified Architectural/Engineering Firm which were approved through the Department of Energy. These reports reflect a project that has been engineered as technologically feasible.

12.2 Economic

A preliminary economic analysis of the project was conducted by determining the projected income of all crop items from the research project plus potential income from new student enrollment due to incorporation of project elements into the Navarro College curriculum.

Due to the limited size of the project on campus property, and because of the restricted injection rate, it was recognized that this would be a pilot project only. As a pilot research project, a payback on investment was not calculated as it would be for a much larger commercial operation.

The chart below reflects a plot of the projected annual income from crop items and student enrollment income compared to the projected annual expenses for the first year of operation.

PROJECTED ANNUAL INCOME		PROJECTED ANNUAL EXPENSES	
Prawns – ¼A x 4000 lbs./A/Yr.		Personnel:	
= 1000 lbs. x $8./lb.	$ 8,000.	1 FTE Aquaculturist	$26,000.
		1 ¼ FTE Secretary	3,600.
Catfish – 2A x 1500 lbs./A		2 Pt. Time Laborers	3,700.
= 3000 lbs. x $1.25/lb.	3,750.	Other Personnel Expenses	8,000.
Greenhouse Produce –		Utilities:	4,000.
10,000 lbs. x $.50/lb.	5,000.		
		Maintenance:	1,500.
New Student Enrollment:	40,000.		
		Communications:	1,500.
		Supplies:	5,000.
TOTAL ESTIMATED INCOME	$56,750.	TOTAL ESTIMATED EXPENSES	$53,300.

These income figures are based on a low end of production and student enrollment and would be considerably higher if yields and enrollment were greater.

13.0 OBTAINING USER COMMITMENT

* No users other than Navarro College.

THIS PAGE INTENTIONALLY LEFT BLANK

14.0 SYSTEM LOADS

This section describes the projected heating and cooling requirements of the project as calculated by an independent engineering firm.

Due to the nature of the project being exploratory and research oriented, very little data was initially available on heating and cooling requirements for aquacultural purposes in this area. Therefore, a vital part of this report has been directed at determining if calculated demands and flows would prove sufficient in this type of application.

14.1 Calculated Heating and Cooling Requirements

In designing the heating system for this project a calculation was determined on the maximum probable heat loss from the aquaculture ponds and greenhouse during a peak demand period. The heat losses experienced in this project consist of (1) heat transmitted through the walls, roofs, and other surfaces and (2) the heat required to warm outside air entering the heated space.

Heat loss for an area is computed by the equation $Q=UA\ (Ti-To)=UA\ T$

where:

Q = heat transfer rate from one area to an adjacent area (pond to air or air to building, etc)

U = heat transfer coefficient (BTU/Hr-ft^2-°F)

A = heat transfer surface area (ft^2)

ΔT = temperature difference between areas (°F)

This equation allows for calculation of heating or cooling requirements of each of the project elements listed below:

A. Aquaculture ponds heat loss

B. Aquaculture ponds heating water

C. Heat exchanger parameters

D. Aquaculture ponds heat gain during heating period

E. Aquaculture facility ventilation rate

F. Pond heat gain during cooling period

G. Greenhouse heat loss and potential heat gain from pond effluents

A. AQUACULTURE PONDS HEAT LOSS

Enclosure Dimension - 204 ft. x 82 ft. x 12 ft.

Total Exposed Area $(A_1) = 2\ (82 \times 12) + 2\ (204 \times 12) + (204 \times 82)$

$A_1 = 1{,}968\ ft^2 + 4{,}896\ ft^2 + 16{,}728\ ft^2$

$A_1 = 23{,}592\ ft^2$

Pond Dimensions - 185 ft. x 30 ft. x 4 ft.

Total Pond Surface Area $(A_2) = 2 \times 185' \times 30'$

$A_2 = 11{,}100\ ft^2$

Heat loss to sides and bottom of pond.

Total Bank Area $= (4 \times 185 \times 4) + (4 \times 30 \times 4)$

$= 3{,}440\ ft^2$

Value of ΔT water-bank = 25°F

U^* Bank = 0.8 BTU/Hr-ft^2-°F

Let Q_3 = Heat Loss to Bank

$Q_3 = 0.8 \times 25°F \times 3{,}440\ ft^2$

Q_3 = 68,800 BTU/Hr

At equilibrium conditions, the pond heat loss will equal that of the enclosure heat loss.

Let Q_1 = Enclosure Loss

Q_2 = Pond loss to enclosure space

T_o = 17°F Temp. outside (peak demand)

T_i = Temp. inside

T_p = 82°F Pond temp.

$$Q_1 = U_1 \times A_1 \times (T_i - T_o)$$

$$Q_2 = U_2 \times A_2 \times (T_p - T_i)$$

$$U_1 \times A_1 \times (T_i - T_o) = U_2 \times A_2 \times (T_p - T_i)$$ ... Pond loss = Enclosure loss

$$U_1 A_1 T_i - U_1 A_1 T_o = U_2 A_2 T_p - U_2 A_2 T_i$$

$$U_1 A_1 T_i + U_2 A_2 T_i = U_2 A_2 T_p + U_1 A_1 T_o$$

$$T_i = \frac{U_2 A_2 T_p + U_1 A_1 T_o}{U_1 A_1 + U_2 A_2}$$

$U_1^* = 1.0$ BTU/Hr-ft^2 - ^{o}F

$U_2^* = 1.0$ BTU/Hr-ft^2 - ^{o}F

* Source: White, Frank M. "Heat Transfer" copyright 1984 by Addison-Wesley Publishing Co., Inc.

$$T_i = \frac{(1 \times 11{,}100\ Ft^2 \times 82°F) + (1 \times 23{,}592 \times 17°F)}{(1 \times 11{,}100\ Ft^2) + (1 \times 23{,}592)}$$

$$T_i = 37.8°F$$

$$Q_2 = U_2 \times A_2 \times (T_p - T_i)$$

$$Q_2 = 1 \times 11{,}100 \times (82-37.8)$$

$$Q_2 = 490{,}620\ BTU/Hr$$

$$\text{Total Loss} = 490{,}620 + 68{,}800$$

$$= \underline{559{,}420\ BTU/Hr}$$

This calculation has assumed no infiltration loss and therefore the actual load will be somewhat higher.

B. AQUACULTURE PONDS HEATING WATER REQUIRED

$$\text{Pond Heat Loss} = 559{,}420\ BTU/Hr = 559{,}420\ lb/hr\text{-}°F \times \frac{1\ \text{gallon}}{8.34\ lb.\ 60\ min/hr}$$

$$\text{Heating Water Required} = \frac{\text{HEAT LOSS}}{500 \times \Delta T\ \text{Geo-pond*}}$$

(freshwater)

$$= \frac{559{,}420}{500 \times 33°F}$$

$$= \underline{\underline{34\ GPM}}$$

* Projects heating water enters at 115°F and pond temp is @ 82°F

C. HEAT EXCHANGER PARAMETERS

Geothermal water temp. entering exchanger = 125°F

Geothermal water temp. leaving exchanger = 70°F

Fresh water temp. entering exchanger = 62°F

Fresh water temp. leaving exchanger = 115°F

Geothermal Heat = 35 GPM x 500 x (125 - 70)

= 962,500 BTU/Hr

$$\text{Freshwater GPM} = \frac{962{,}500 \text{ BTU/Hr}}{500 \times (115-62)}$$

$$= \underline{36 \text{ GPM}}$$

D. AQUACULTURE PONDS HEAT GAIN DURING HEATING PERIOD

Heat gain = Solar gain + Transmission

Exposed Area = N - 204 x 9 = 1836

E - 82 x 9 = 738

S - 204 x 9 = 1836

W - 82 x 9 = 738

Hor - 204 x 82 = 16,728

Solar Gain Factors = N - 30 BTU/Hr-Ft^2

E - 77

S - 72

W - 90

Hor - 205

Solar Gain = 1836 (30 + 72) + 738 (77 + 90) + 16,728 (205)

= 187,272 + 123,246 + 3,429,240

= 3,739,758 BTU/Hr

Transmission Gain = (2 x 1836) + (2 x 738) + 16,728 x 1.0 BTU/Hr - Ft^2-°F x 20°F

= 437,520 BTU/Hr

Total Gain = 3,739,758 + 437,520

= 4,177,278 BTU/Hr

E. AQUACULTURE FACILITY VENTILATION RATE

Total Heat Gain = 4,177,278 BTU/Hr

If a max. temp. rise of 20°F in the aquaculture building is allowed,

$$\text{Vent rate} = \frac{4,177,278}{1.08 \times 20°F} = 193,392.5 \text{ CFM}$$

$$10 \text{ Fans used} = 193,392.5 \div 10$$

$$= 19,340 \text{ CFM/FAN}$$

F. POND HEAT GAIN DURING COOLING PERIOD

Assuming enclosure temp. is 120°F and water temp. is 82°F with an h-value of 1 BTU/Hr-Ft^2-°F

$$\text{Pond Heat Gain} = h \times A \times T$$

$$= 1 \times 185 \times 60 \times 20$$

$$= 222,000 \text{ BTU/Hr}$$

$$\text{Cooling water flow required} = \frac{\text{Heat gain}}{500 \times \Delta T}$$

$$\text{Cooling water} = 222,000 \quad (500 \times 20)$$

$$= \underline{\underline{25 \text{ GPM}}}$$

G. GREENHOUSE HEAT LOSS AND POTENTIAL HEAT GAIN FROM POND EFFLUENT

Enclosure area = 30' x 108'

Surface area = N (2 x 8' x 108') + (2 x 10' x 30') + (30 x 108)

= 1728 + 600' + 3240

= 5568 Ft^2

With a U-Factor of 1 BTU/Hr-Ft^2-°F and a 30°F temp. difference (20° outside 50° inside)

Heat Loss = 1 x 5568 x 30

= 167,040 BTU/Hr

Pond effluent temp. of 80°F and a flow at 30 GPM with a delta T through the Greenhouse Heaters.

Available heat = 30 GPM x 500 x 10

= 150,000 BTU/Hr

Due to additional infiltration loss, the Greenhouse will require additional heating but sufficient heat should be available for Spring and Fall heating requirements.

THIS PAGE INTENTIONALLY LEFT BLANK